



Wavelength Shifting Liquid-Filled Capillaries for Optical Electromagnetic Calorimetry Applications

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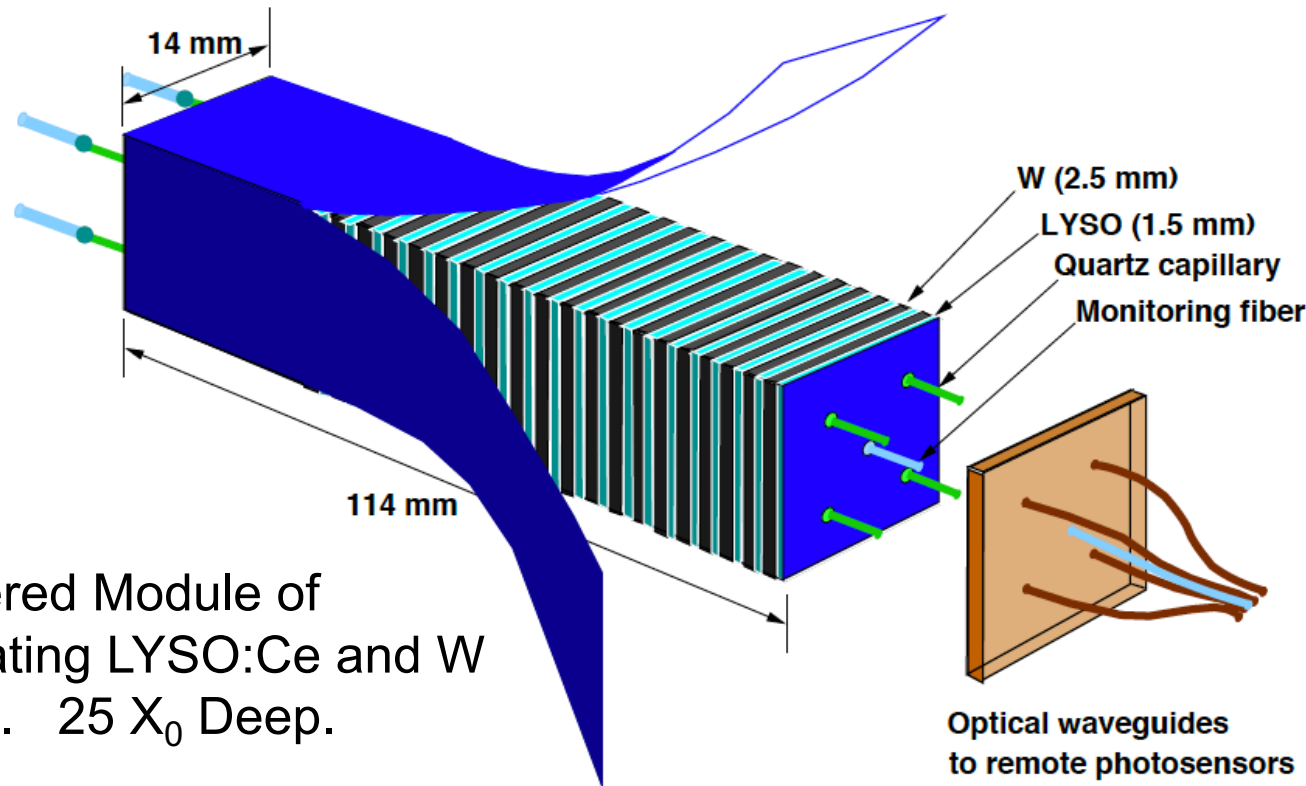


Outline

- Challenge – optical readout under high radiation conditions
 - Example application to EM calorimetry in a sampling calorimetry structure
- Development and refinement of the capillary technique
 - WLS Dye Investigations
 - Capillary Structure Investigations
 - Irradiation studies
- Comment on further development and refinements



An Example Application: Compact EM Calorimetry



A Layered Module of Alternating LYSO:Ce and W Layers. $25 X_0$ Deep.

Shashlik Readout Approach Considered by CMS for Endcap EM Calorimetry.

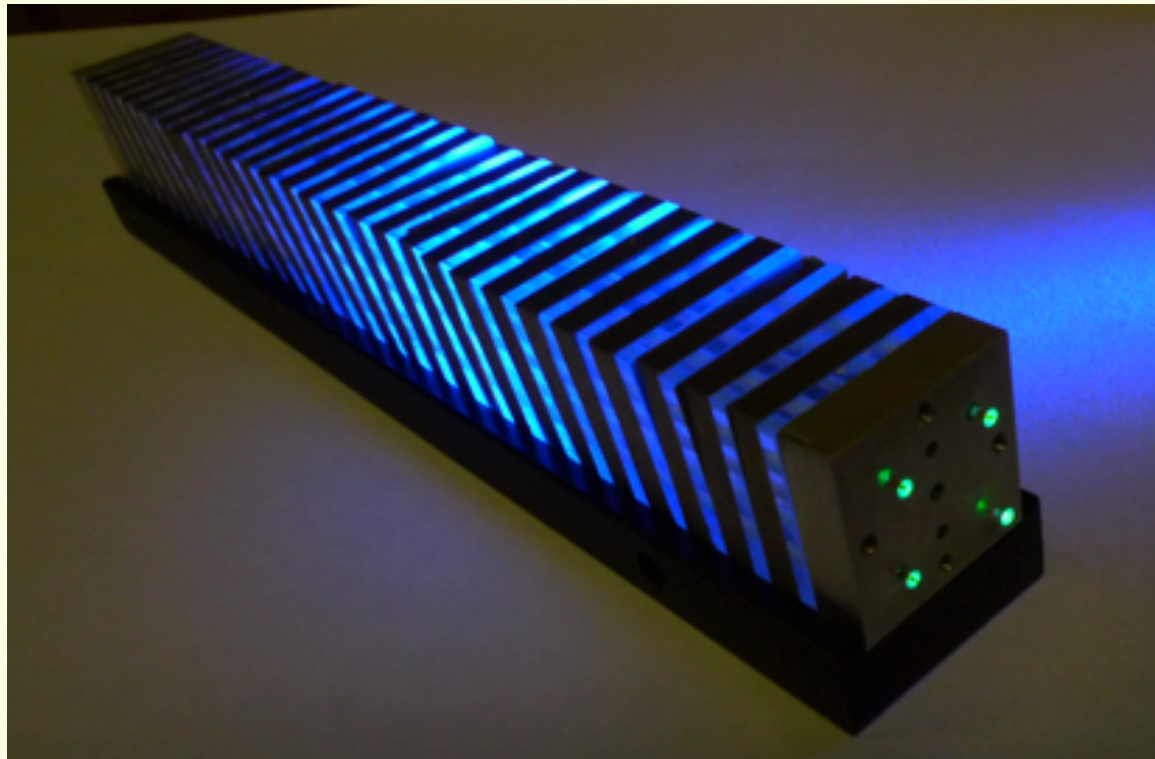
LHC Endcap at $\eta \sim 3$ and 3000 fb^{-1} :

Ionization Dose $\sim 150 \text{ Mrad}$

Neutron Fluence $\sim 10^{16} \text{ n/cm}^2$



A Layered W/LYSO:Ce Optical Module



29 Layers LYSO:Ce (1.5mm thickness)

28 Layers W (2.5mm thickness)

Fiberoptic WLS Elements to wave shift the light from LYSO (425nm) to convenient blue-green wavelength (495nm) for photosensors.

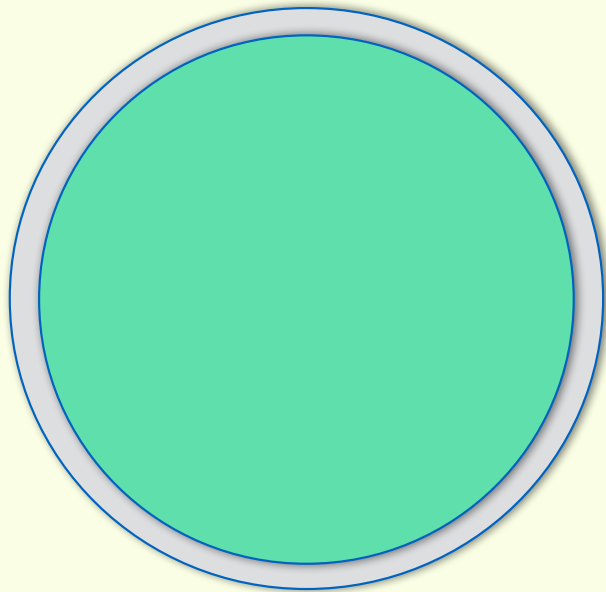
WLS Options: DSB1 and J2 (similar to Y11/K27)

Challenge: How to make the WLS Fiber-optics radiation hard enough



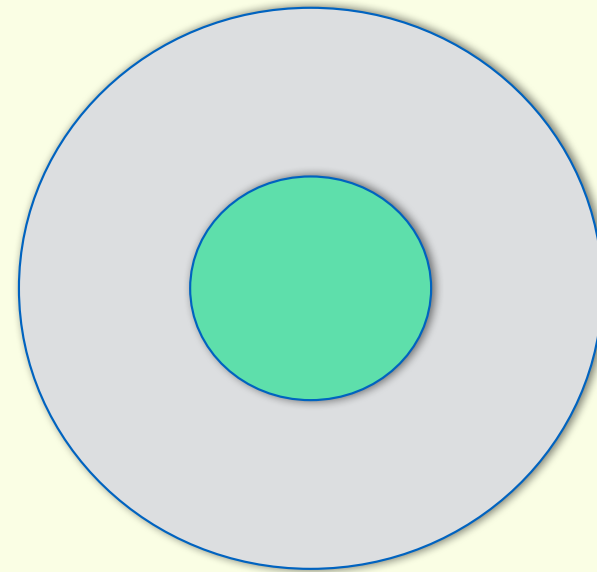
Revisiting the Fiberoptic Profile

Conventional Optical Fiber



- Optical Path in WLS medium is maximal.
- Whole structure – typically polymer - is not rad hard.

Thick Wall Profile

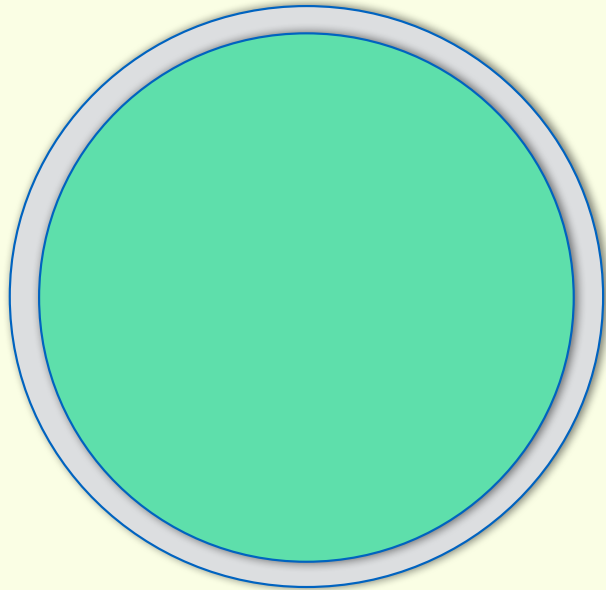


- Optical Path in WLS medium is significantly reduced.
- High OH⁻ rad hard Quartz.
- Core liquid is generally more rad hard than polymer.



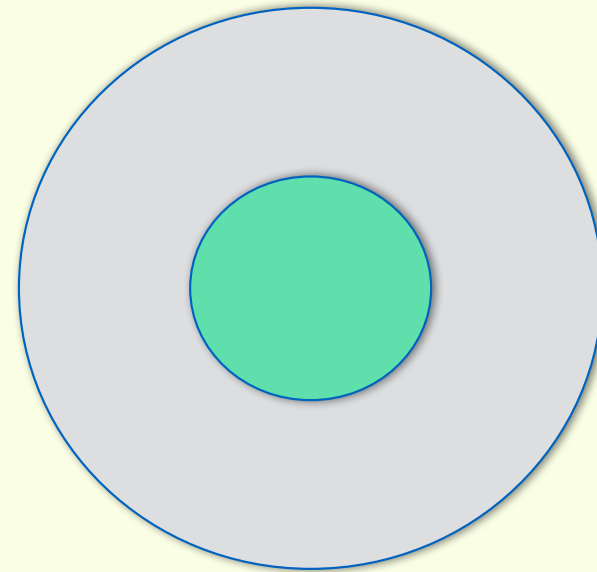
Revisiting the Fiberoptic Profile

Conventional Polymer
Multi-Clad Optical Fiber



Core Index $n = 1.59$
Cladding Index $n = 1.43$
Outer surface air $n \sim 1$
For OD = 1mm
Cladding Thickness $\sim 30\mu\text{m}$

Thick Wall Quartz
Liquid Core Capillary Profile

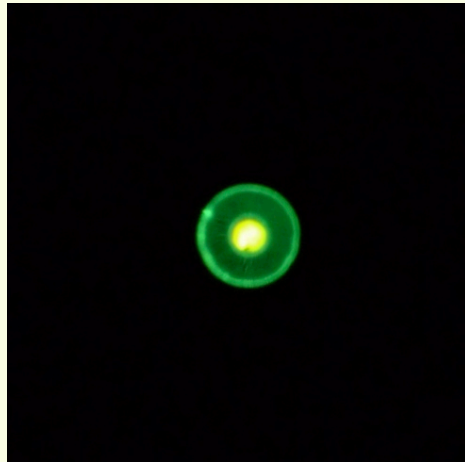


Core Index $n = 1.57$
Cladding Index $n = 1.46$
Outer surface air $n \sim 1$
For OD = 1mm
Cladding Thickness $\sim 300\mu\text{m}$

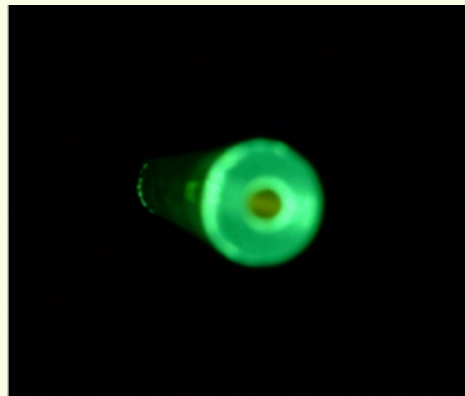


Multi-clad Organic Optical Fiber Irradiated

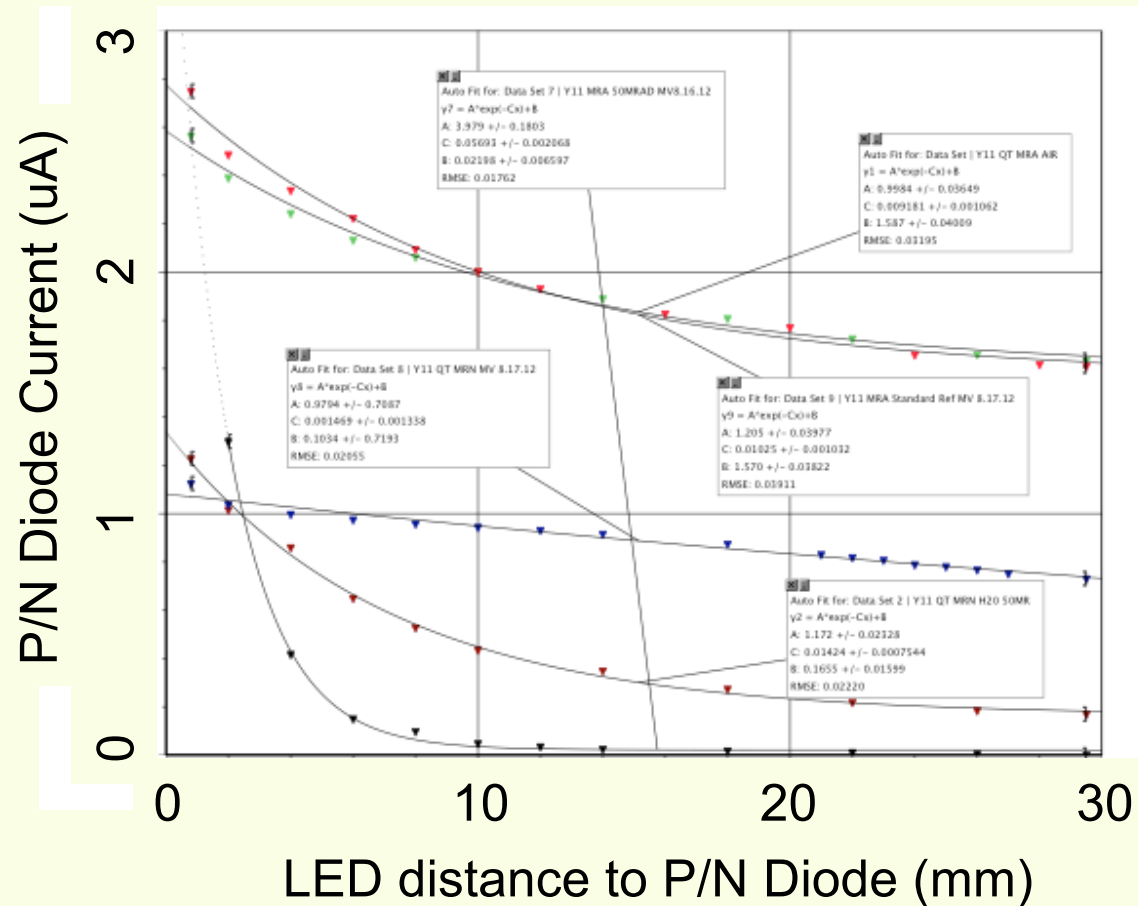
Irradiation study of a Y11 WLS Fiber from Kuraray of 0.94mm OD.
Before and after irradiation with 50Mrad of ^{60}Co gammas.



Head on view.



View at $\sim 30^\circ$

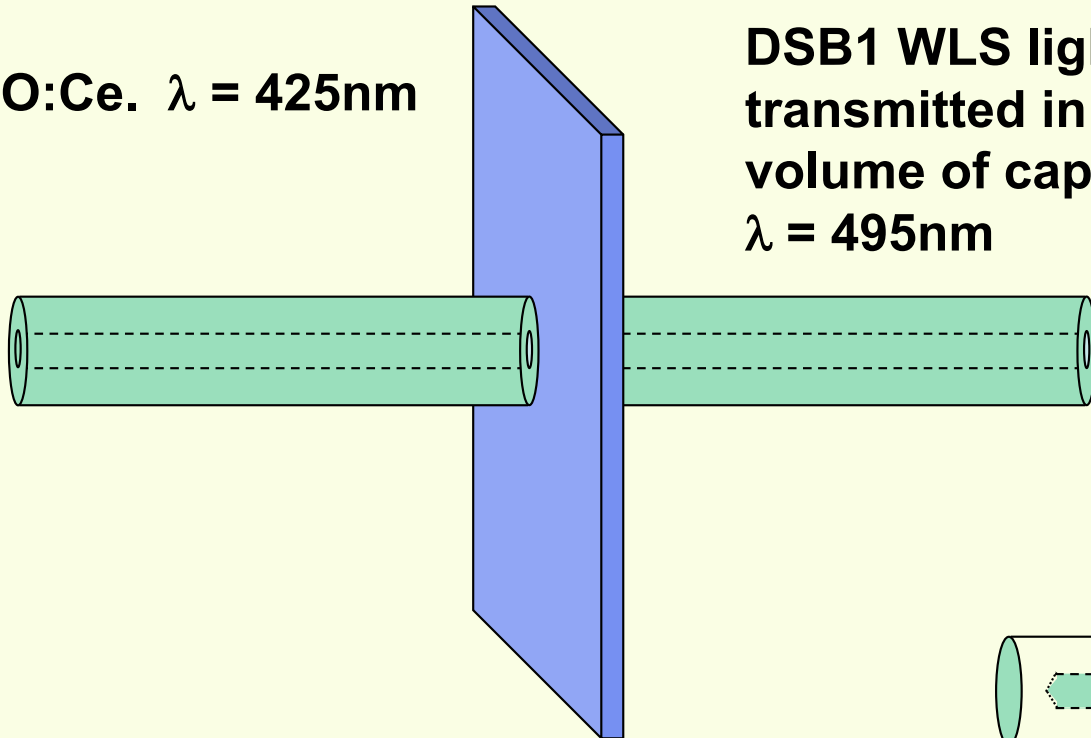


Fiber in a Quartz tube with water wetting fiber and tube surfaces.



Waveshifting light from scintillation tiles

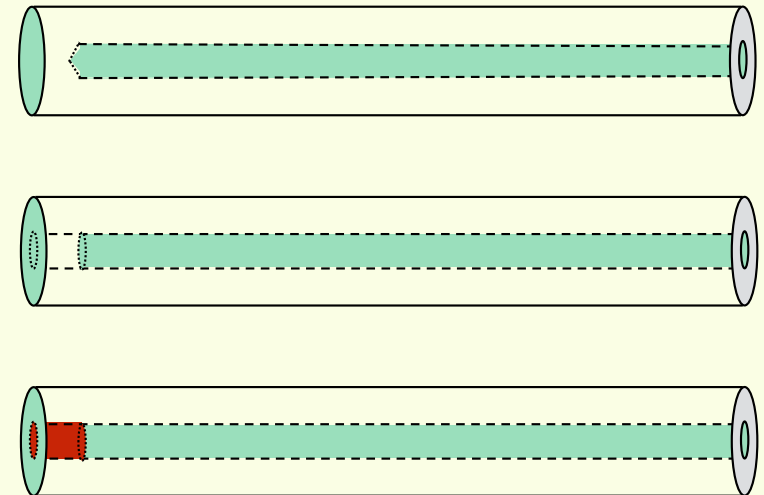
LYSO:Ce. $\lambda = 425\text{nm}$



DSB1 WLS light
transmitted in full
volume of capillary
 $\lambda = 495\text{nm}$

Three Fusion Types:

1. End fusion
2. Clear Quartz Core Insert
3. Ruby Quartz Core Insert



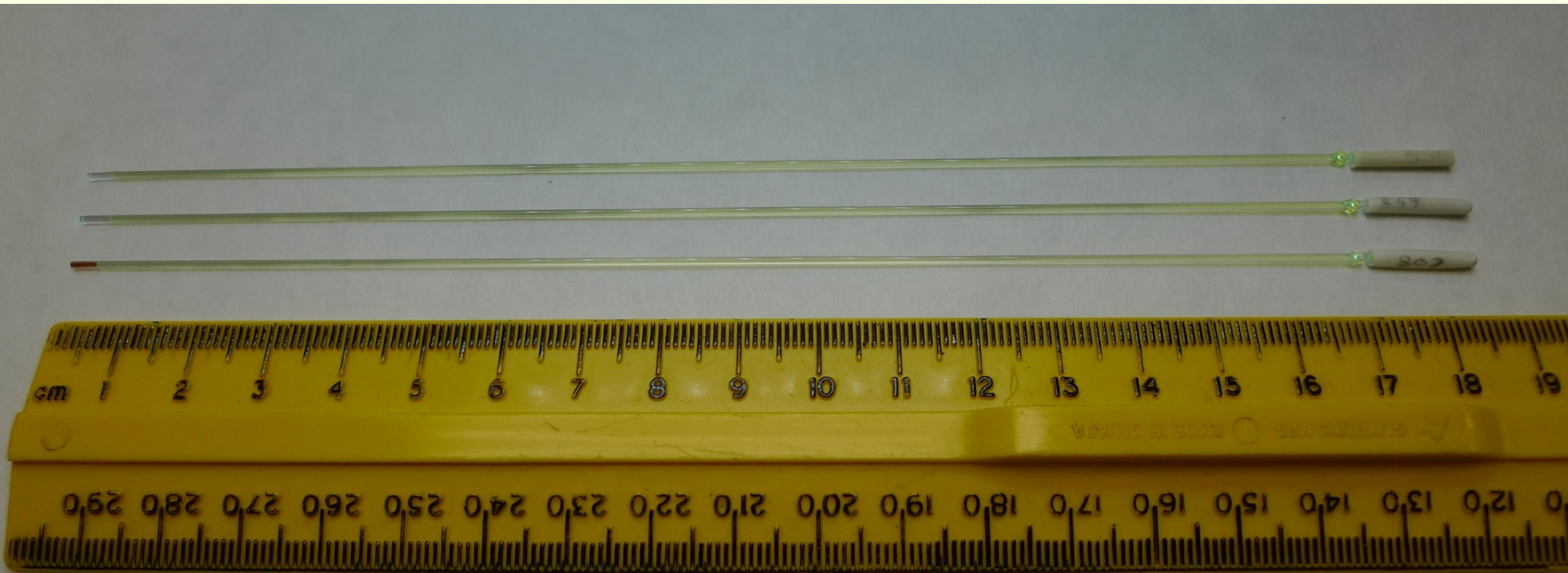


Side View of Capillaries

LENGTH 18.5cm

OUTER DIA. 1mm

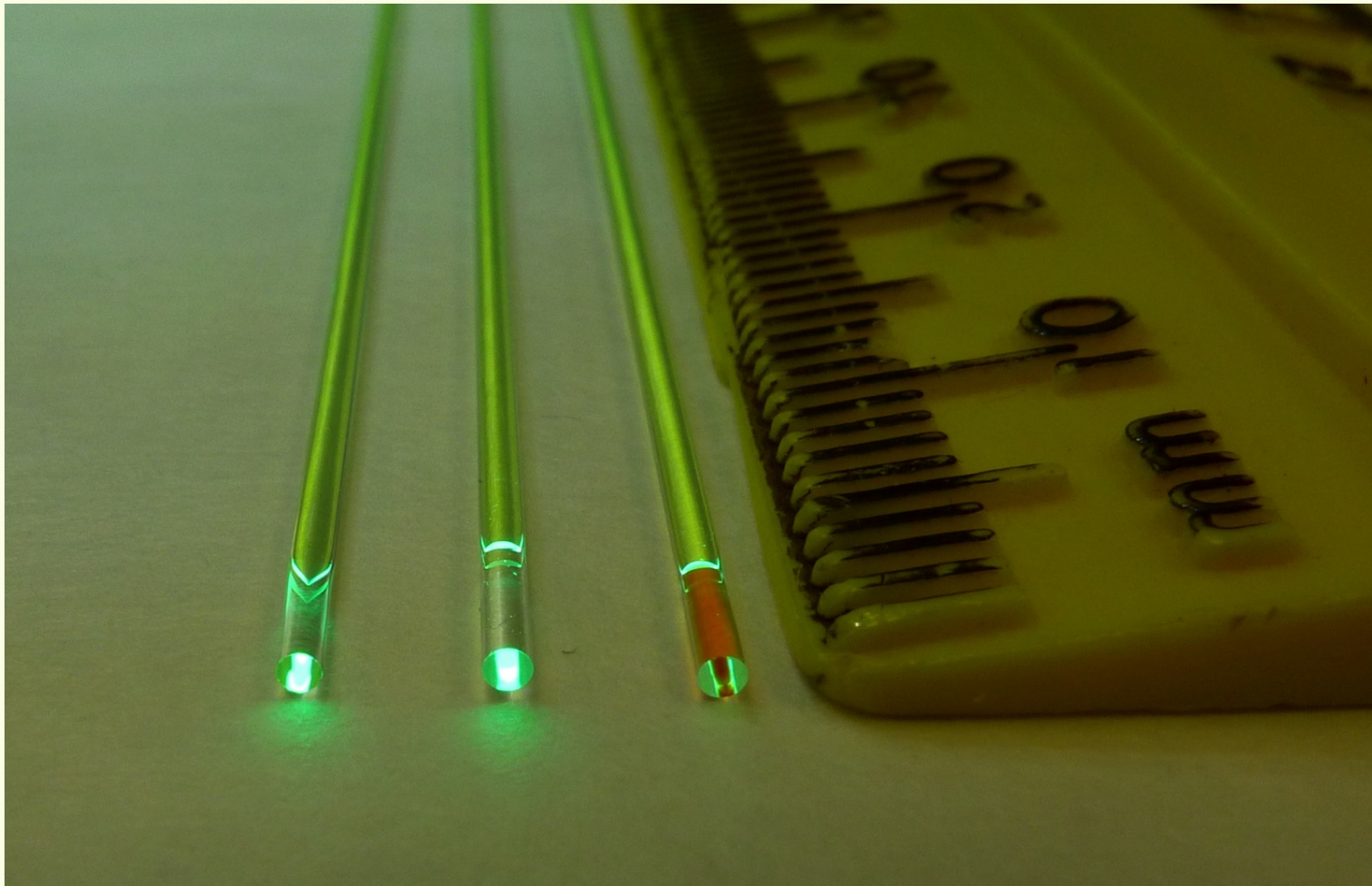
CORE DIA. 0.4mm





Capillary Readout End

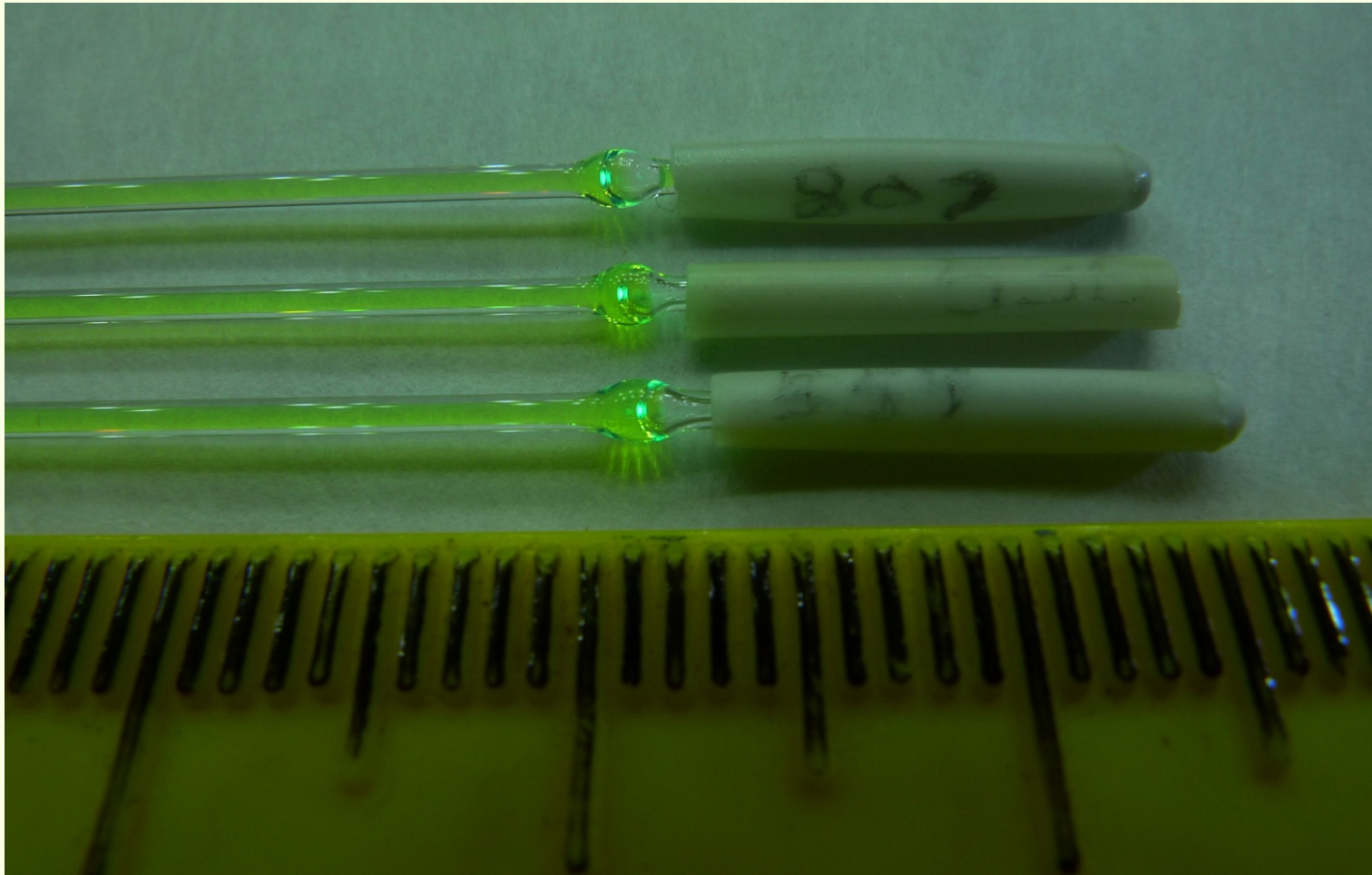
Ends Thermally Fused and Optically Ground Before Liquid Fill





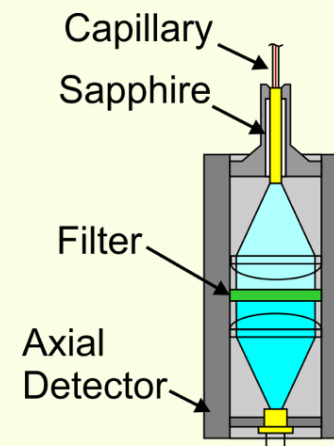
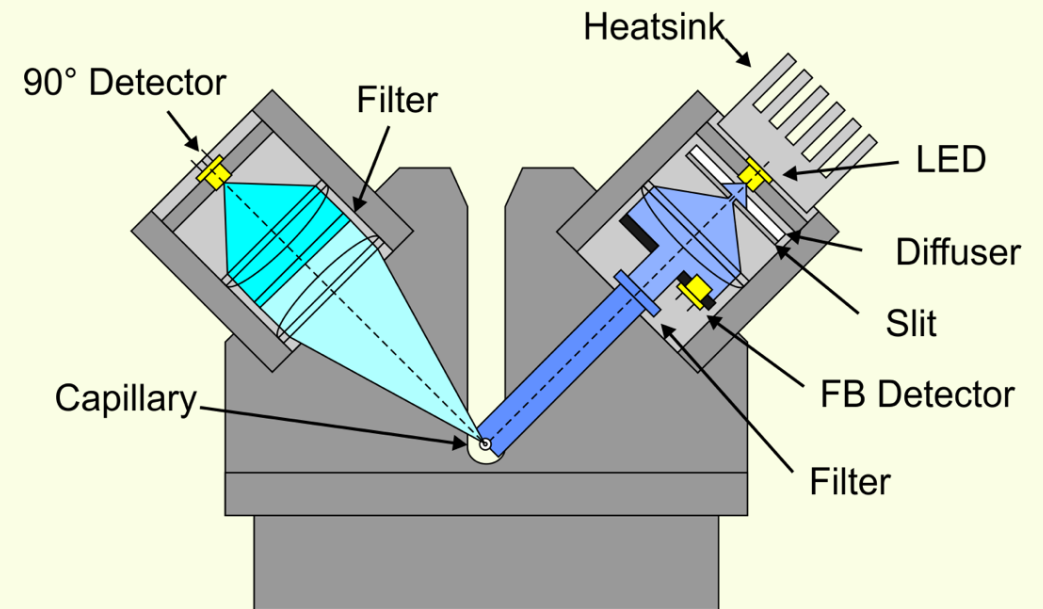
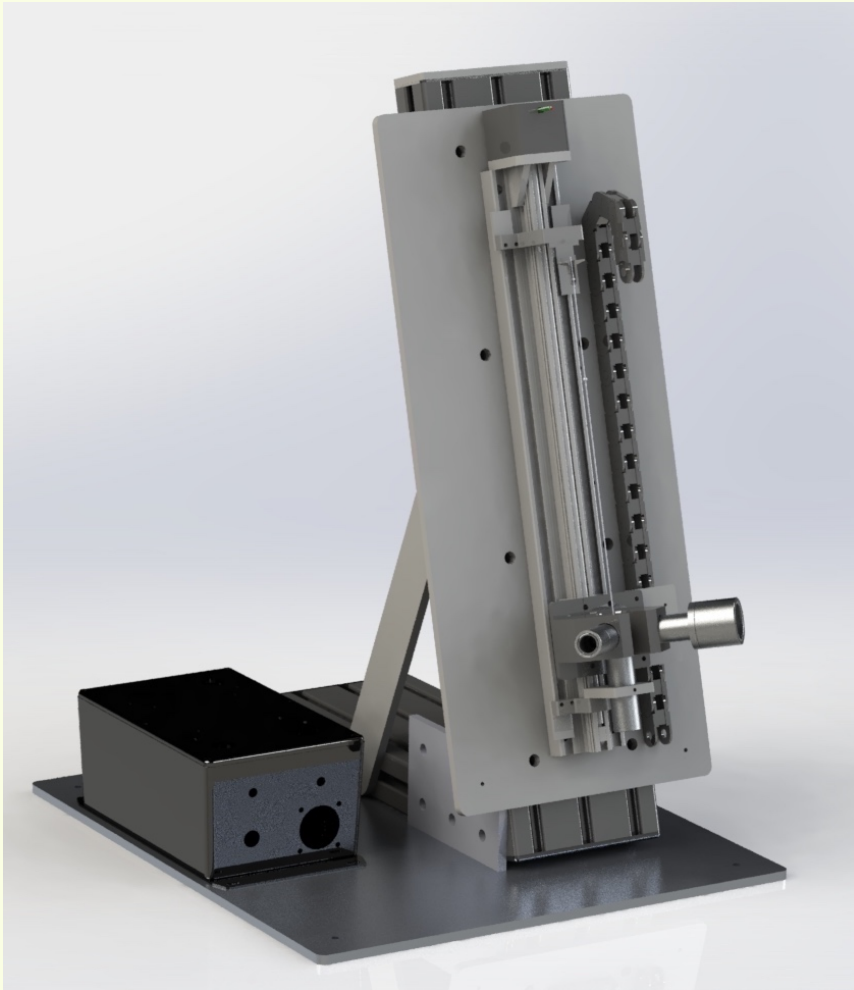
Non-Readout End

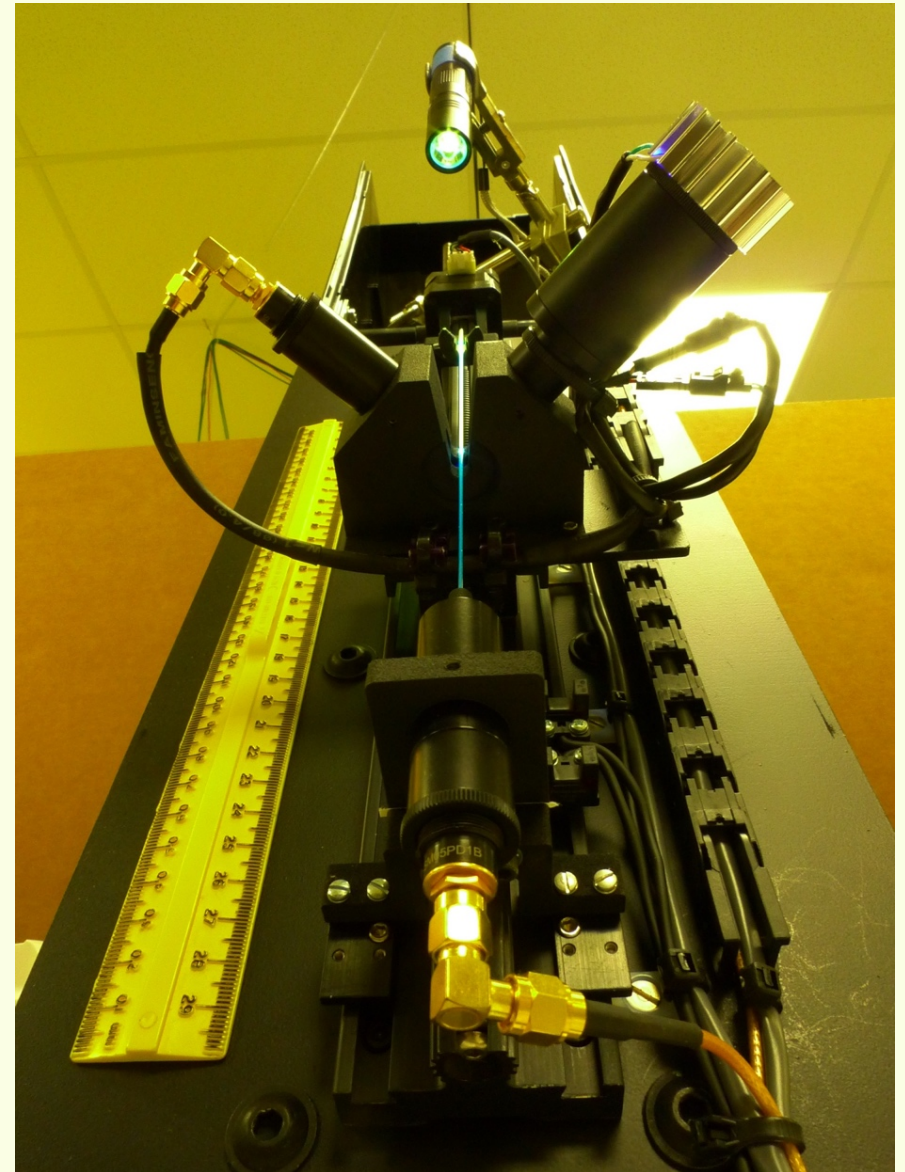
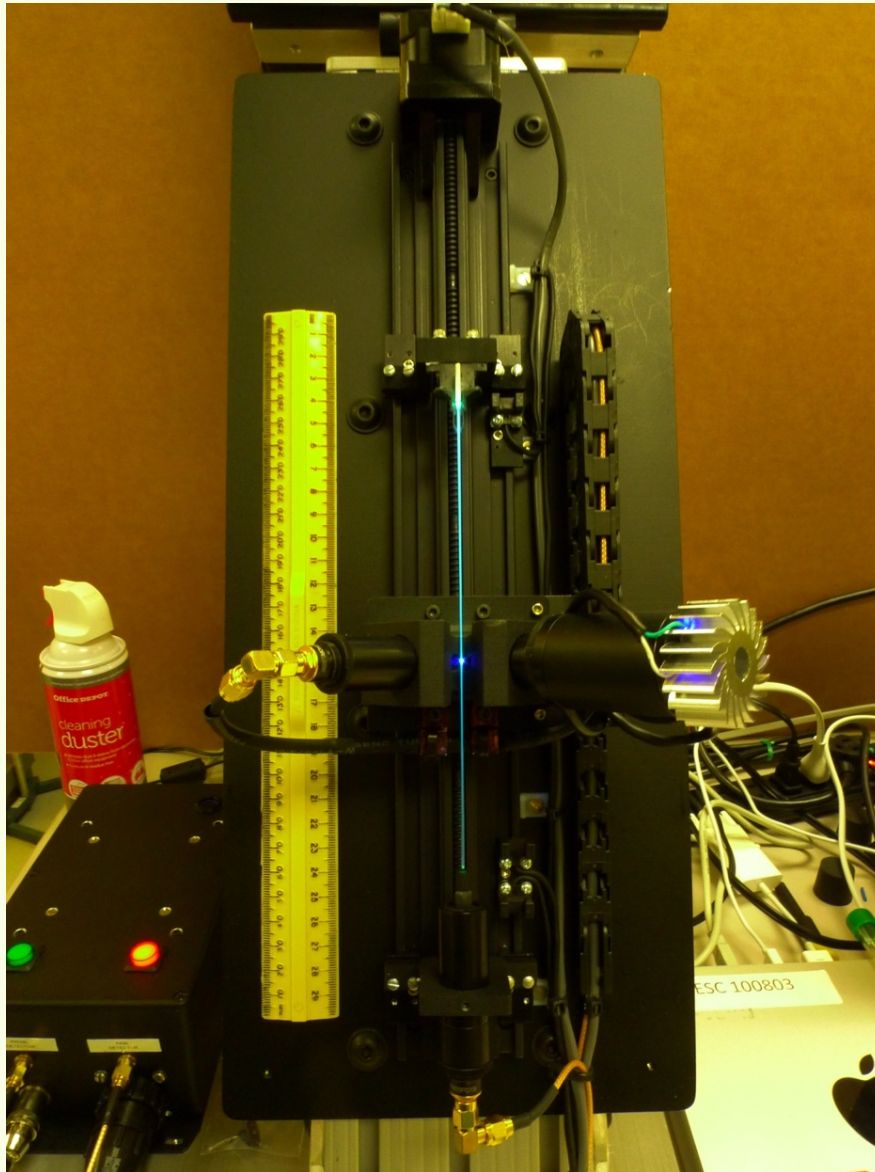
Fluid expansion reservoir - blown into C\capillaries prior to Readout End preparation and liquid fill.
After liquid fill, epoxy sealing here to avoid liquid damage.





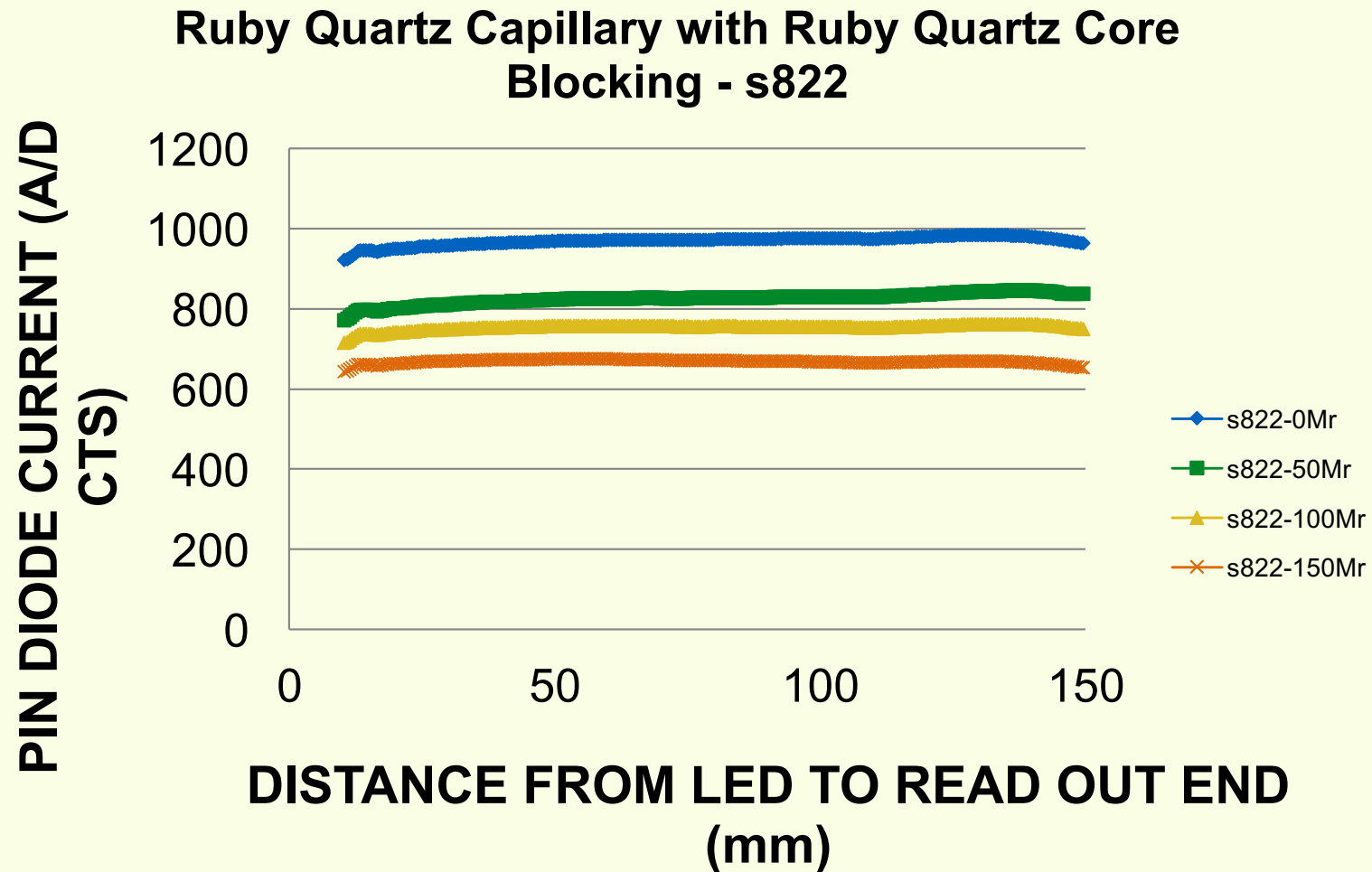
Capillary Test Apparatus







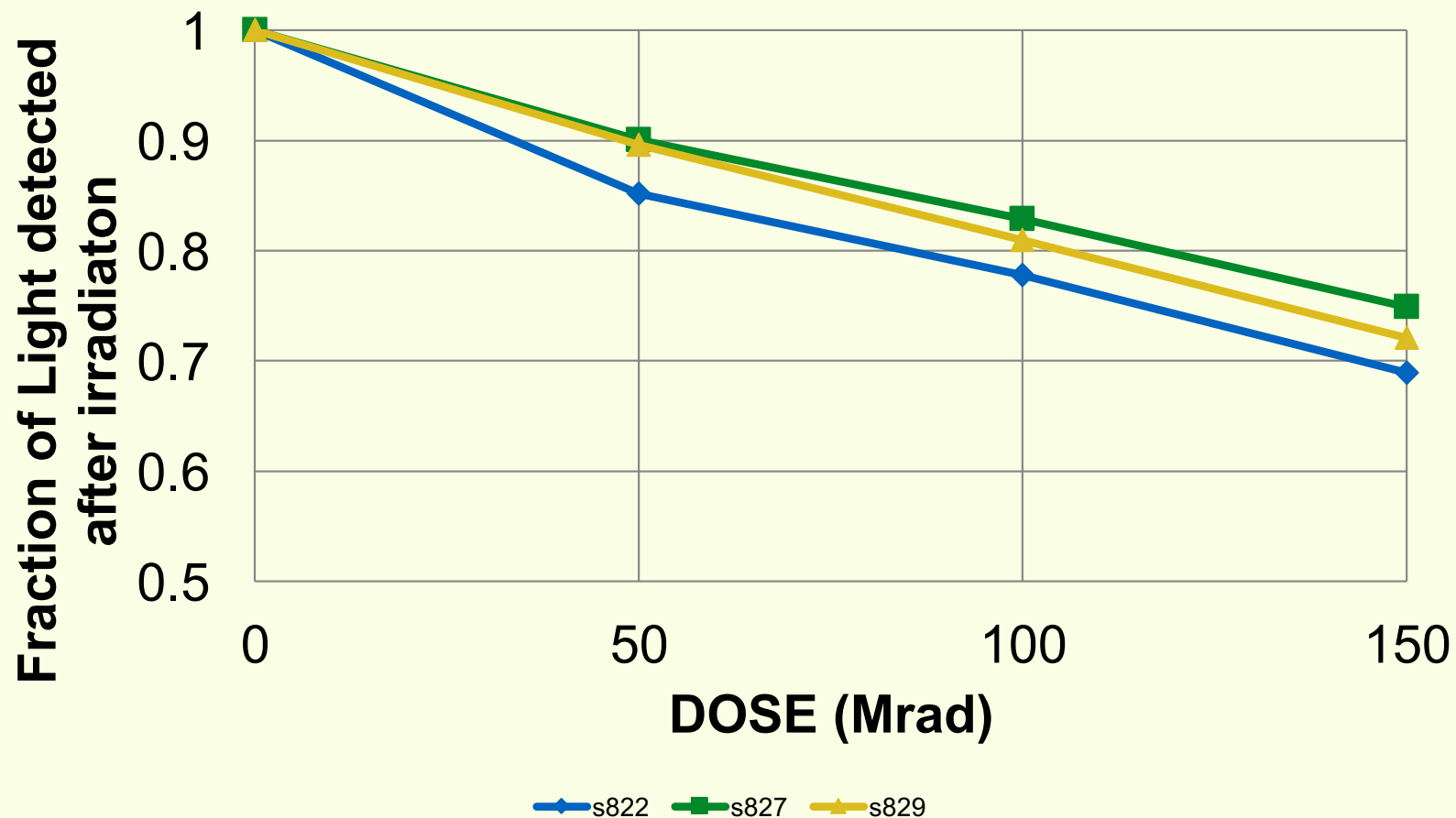
Co-60 Irradiation Study – Capillaries with Ruby Quartz Inserts at the Readout End





Co-60 Irradiation Study – Capillaries with Ruby Quartz Inserts at the Readout End

Light Transmission as a Function of Co-60 Radiation Dose



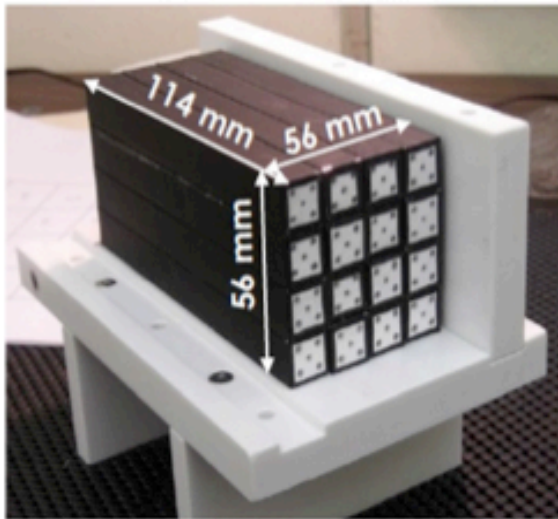


A 4x4 array of W/LYSO:Ce with DSB1 WLS Capillaries

Beam Test
Caltech, Iowa
Notre Dame
Virginia

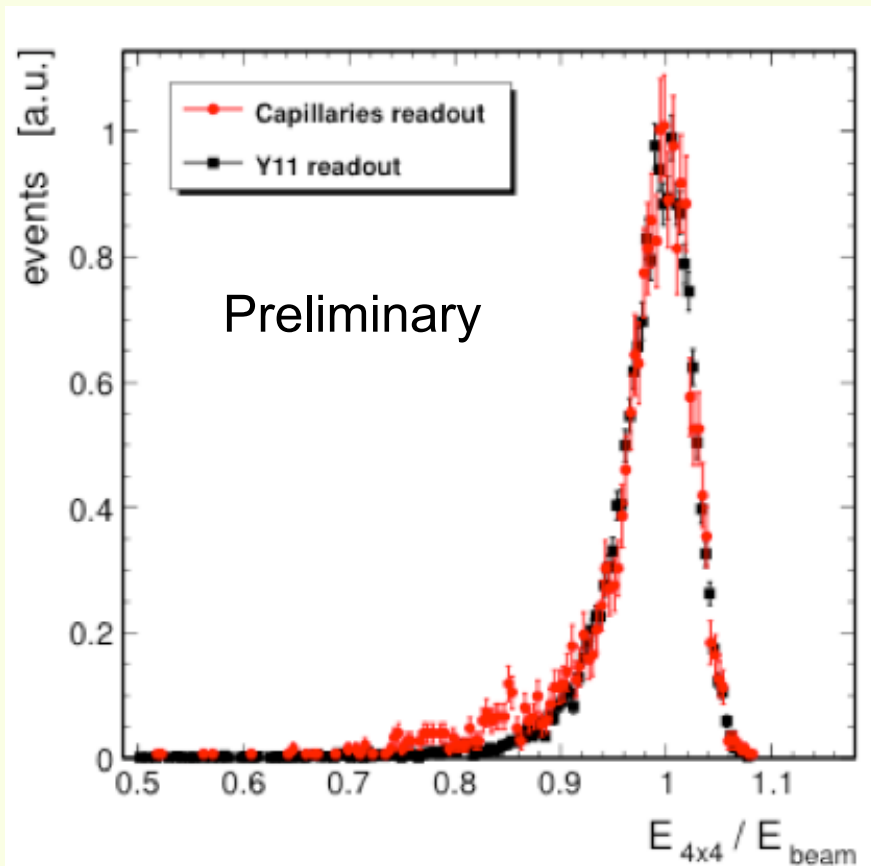
Array tested at CERN H4 and
performance compared with
earlier measurements using
Y11 WLS fibers.

BEAM
↓

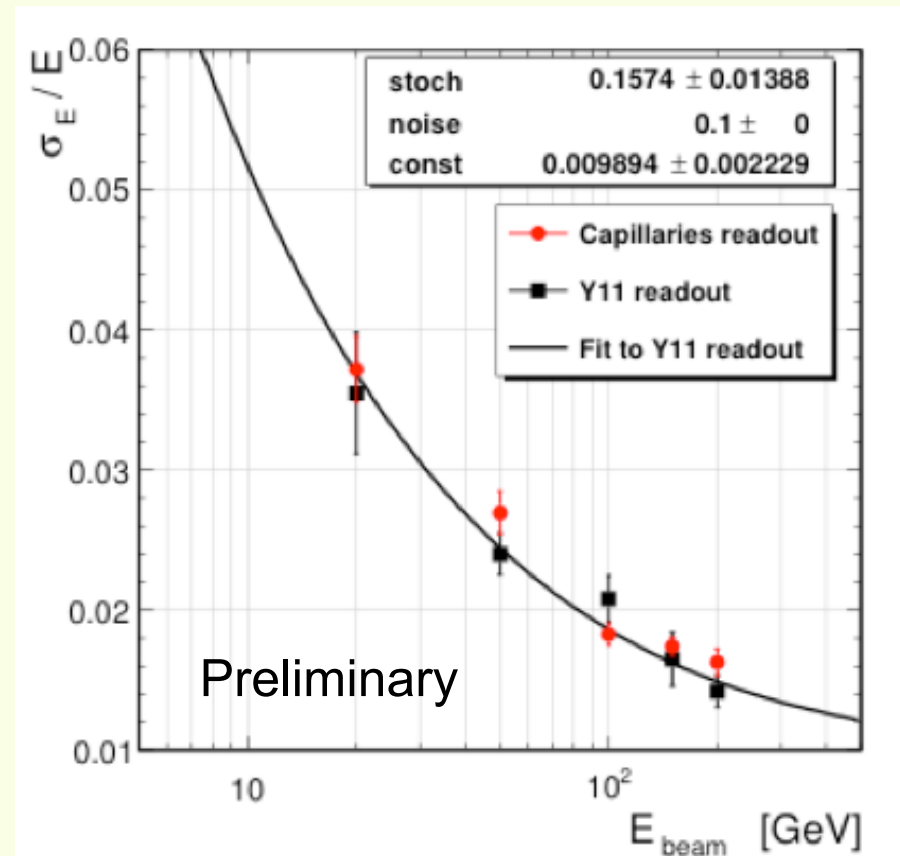




Energy Resolution of the compact 4x4 array of W/LYSO modules.



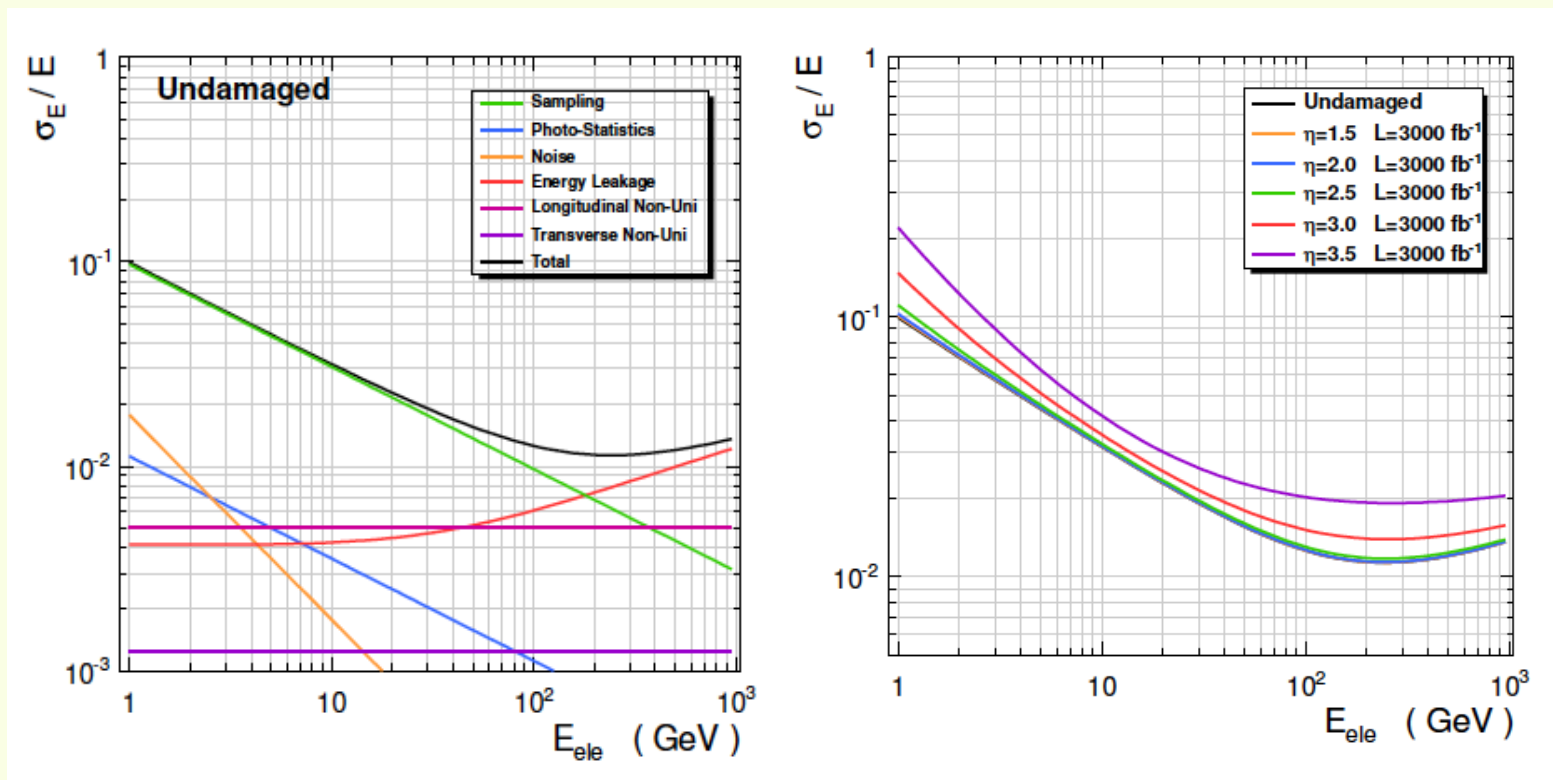
Measured 4x4 energy compared to the CERN H4 beam energy for 100 GeV electrons.



Energy resolution vs electron beam energy. CERN H4.



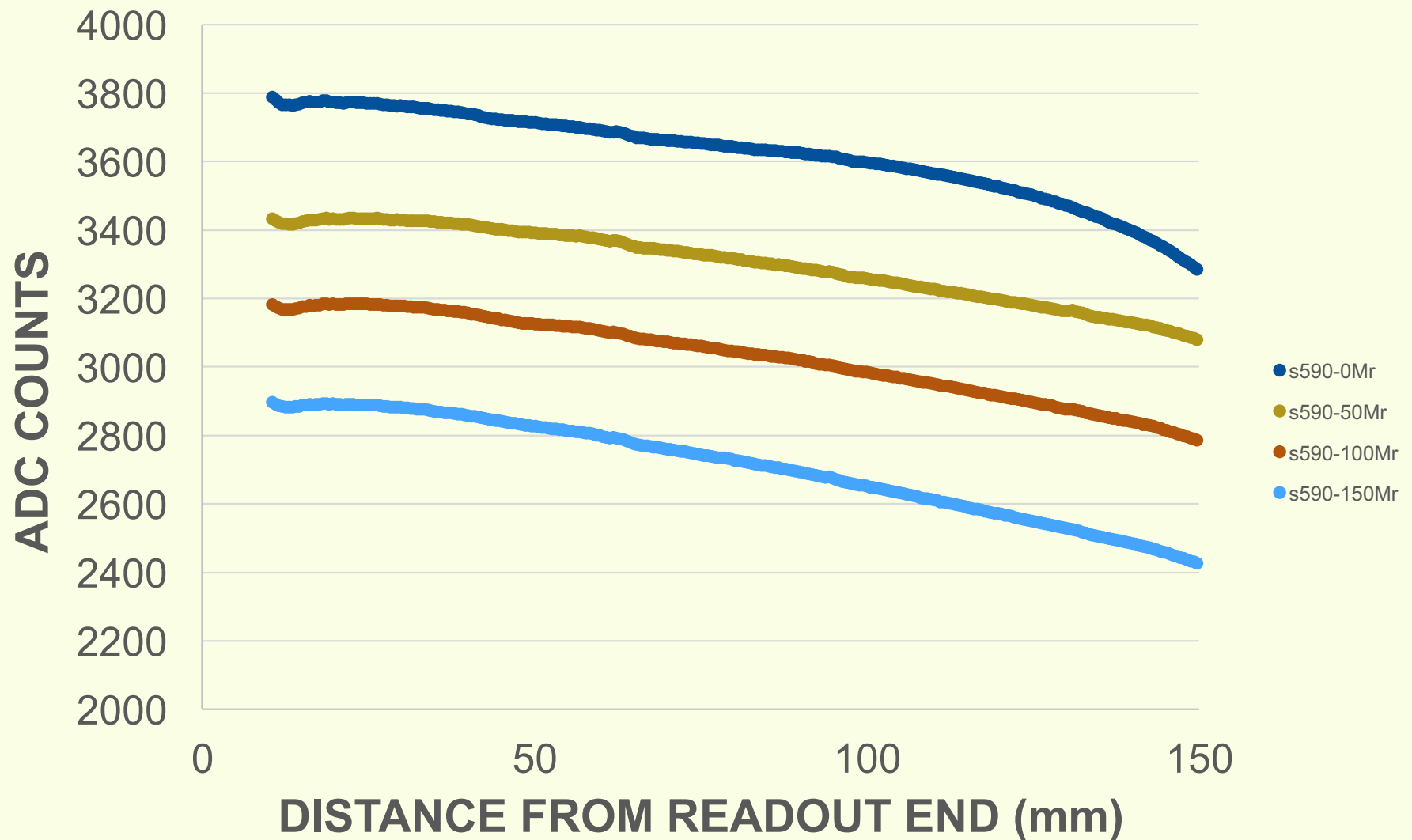
Energy Resolution



Plots from A. Ledovskoy, Virginia



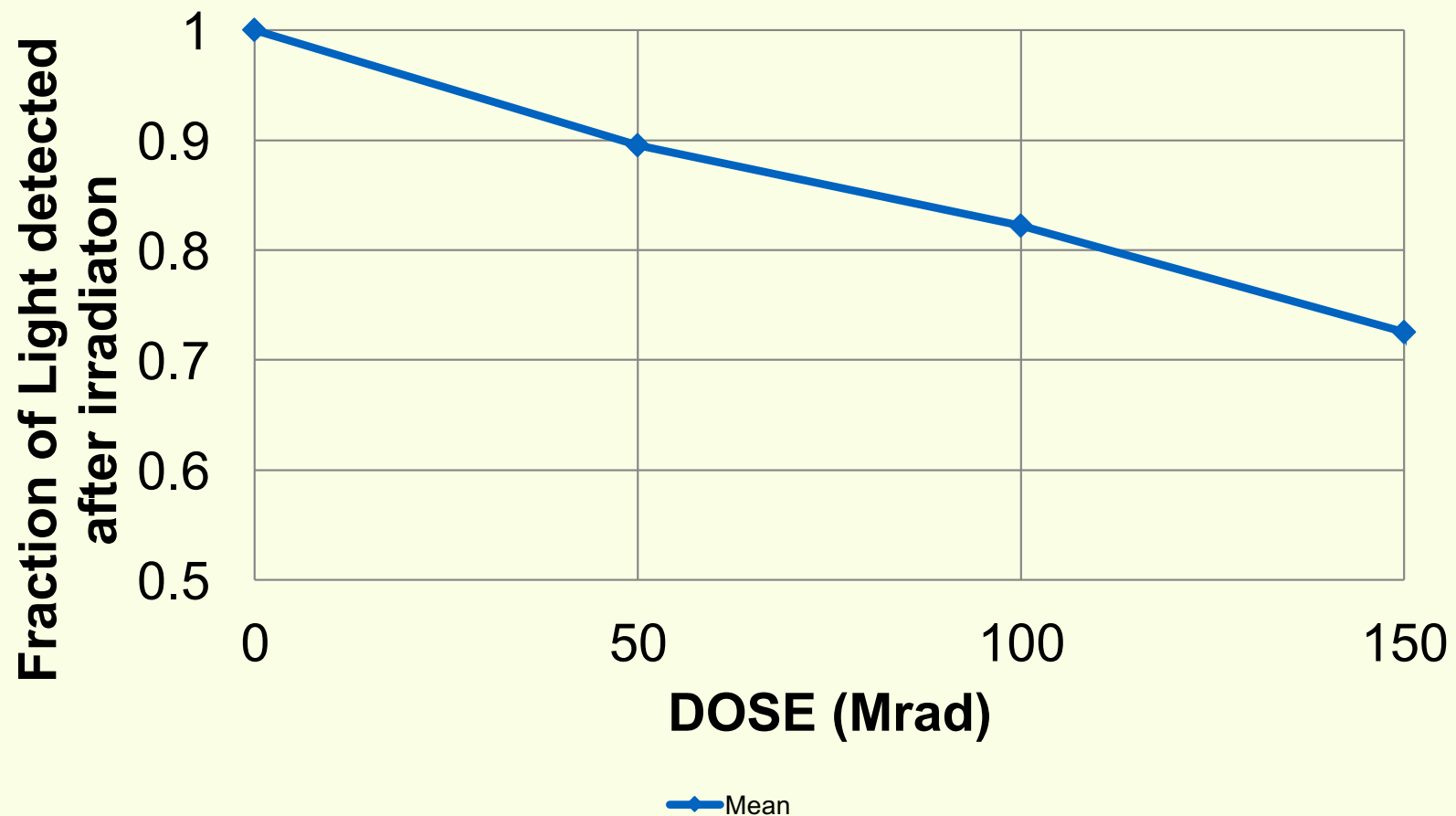
CAPILLARY WITH CLEAR QUARTZ INSERT AT READOUT END - S590





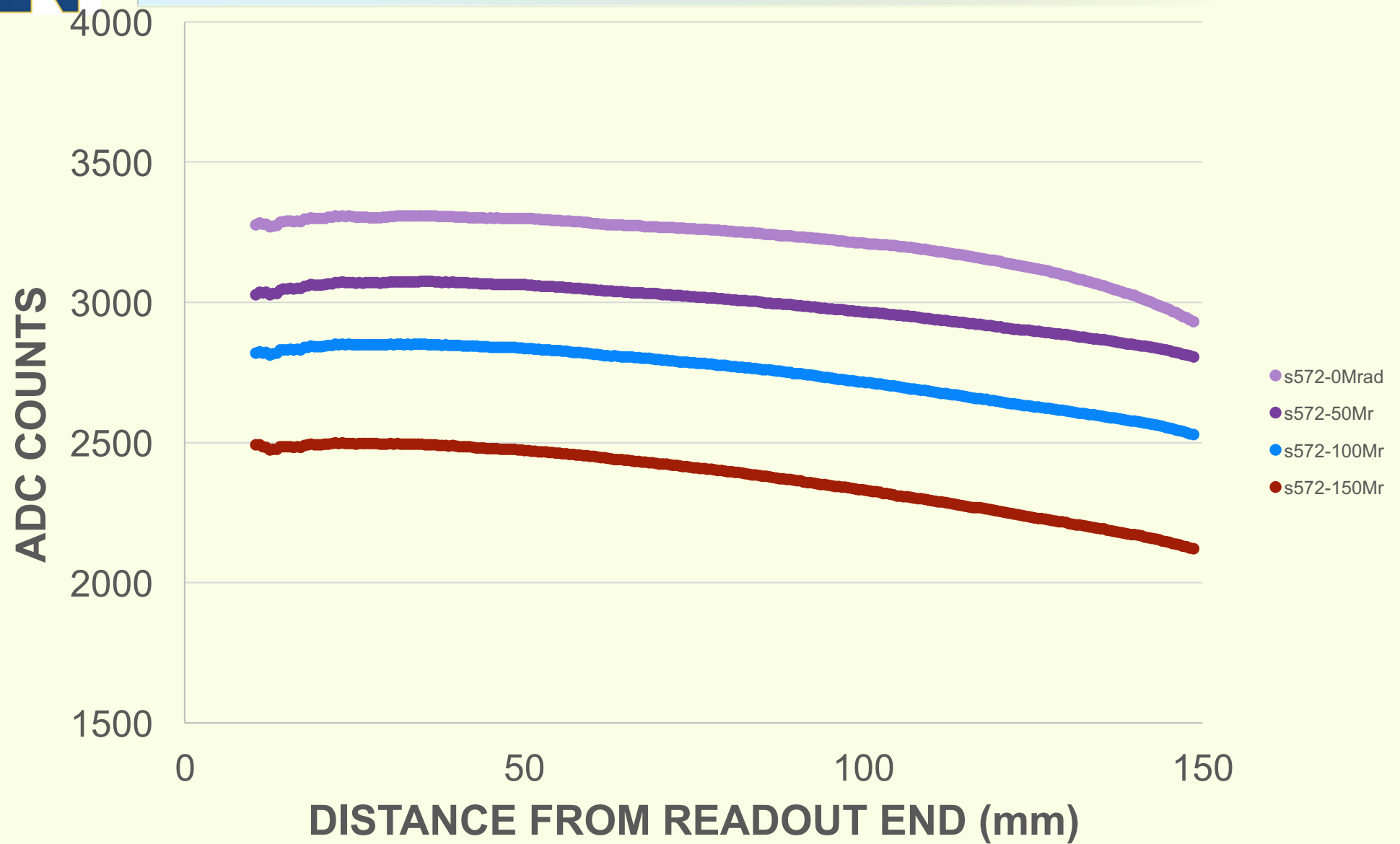
Co-60 Irradiation Study – Capillaries with Clear Quartz Inserts at the Readout End

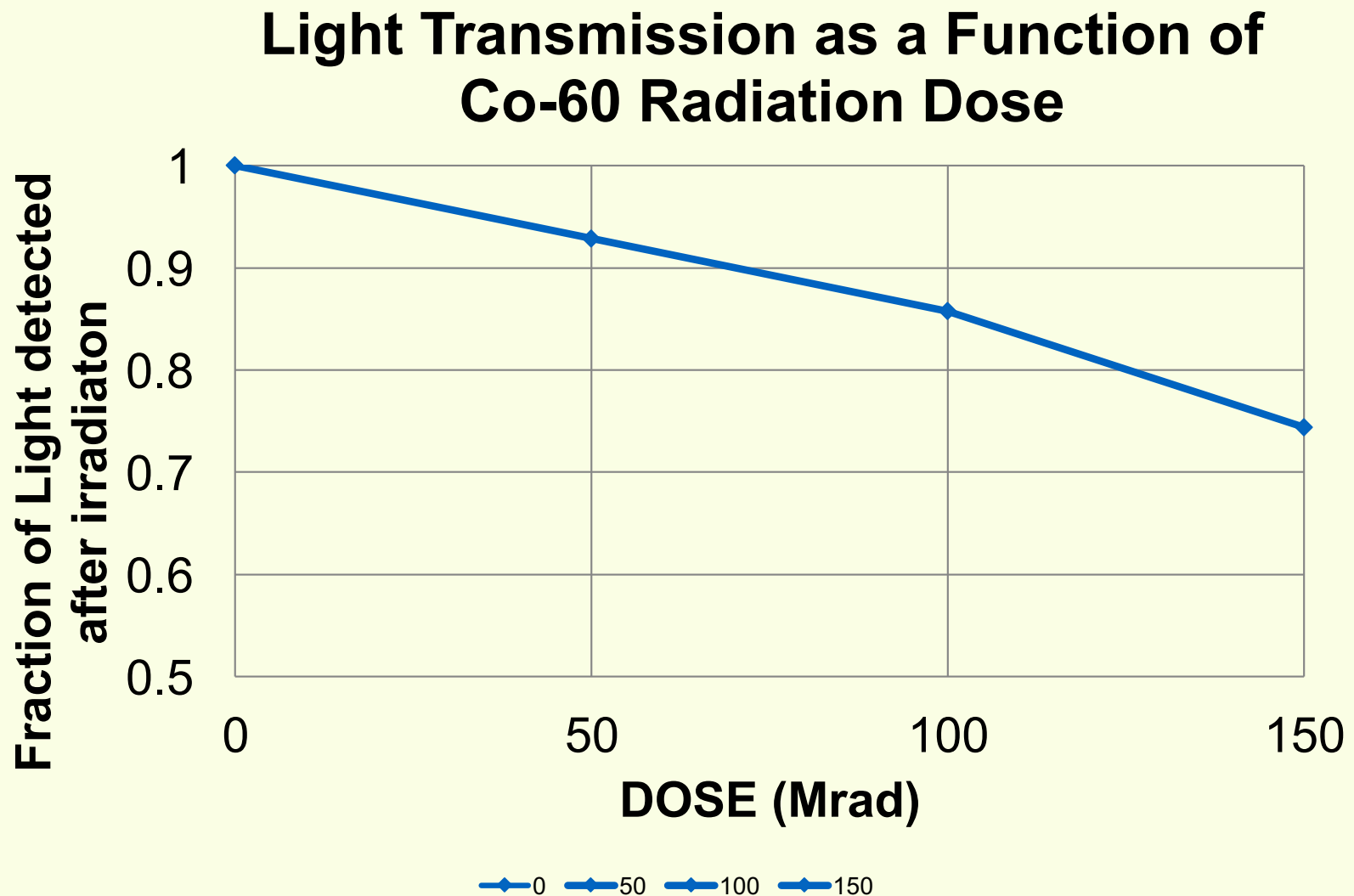
Light Transmission as a Function of Co-60 Radiation Dose





CAPILLARY WITH FUSED READOUT END - s572







Summary

1. Capillaries can provide a high radiation resistant readout approach for optical sampling detectors such as EM calorimetry
2. Under gamma ray exposure, currently fabricated structures deliver 70% of the original light after 150Mrad of dose.
 - Primary effect appears to be a reduction in the overall efficiency of the waveshifting process
 - Secondary effect is an observed but modest increase in the optical attenuation of light propagating in the core liquid.
3. The greatest longitudinal uniformity is provided by optical core blocking, provided in these studies by ruby Quartz inserts fused into the core.
 - Good choice for minimizing the constant term in energy resolution
4. The greatest light transmission is provided by clear Quartz inserts fused into the core. Provides a factor of x3 increase in light collection.
 - Potential benefits for fast timing from sampling calorimetry structure
5. Systematics under detailed study



Ongoing and Future Work

Currently in progress:

1. Fabrication and uniformity and systematic studies
 - Improved efficiency and longitudinal uniformity including timing
2. Irradiation Studies:
 - Gamma Irradiation up to 250 Mrad (at Notre Dame)
 - Proton Irradiation up to $10^{15}/\text{cm}^2$ (at LANL coord. by Caltech, RY Zhu)
3. Waveshifter studies:
 - Spectrophotometry before and after irradiation
 - J2 – filled capillaries for efficiency and uniformity.
 - 3HF (and variations) and other WLS dyes – in filled capillaries
4. Planned - comparisons with Slitrani simulations of these structures.



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